Analysis of 24" and 36" Diameter
Cast-In-Place Concrete Pipe
Under Live Loading

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SUMMARY

An engineering analysis was performed to determine if 24" and 36" diameter cast-in-place concrete pipe (CIPCP) could support typical construction traffic loadings with cover over the pipe ranging from 1 1/2 feet to 2 feet. Three types of loading were used: the AASHTO H20 loading, a fully loaded CAT 623E scraper, and a fully loaded CAT 637E scraper. The soil conditions used in this analysis were based on those at the Chandler Airport as reported by Western Technologies Inc. (WTI).

The results of the analysis indicate that both sizes of pipe may handle the H20 loading at either depth of cover. However, both pipe sizes are probably incapable of handling the fully loaded scrapers with only 1 1/2 feet of cover. With 2 feet of cover, the 36" pipe may handle both scraper loads while the 24" may handle only the loading of a 623E.

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SCOPE OF ANALYSIS

The purpose of this report is to present the results of a structural analysis performed on 24" and 36" diameter cast-in-place concrete pipe (CIPCP) under various construction traffic loading conditions with cover over each pipe ranging from 1 1/2 feet to 2 feet. Three types of loading were considered: an AASHTO H20 loading, a fully loaded Caterpillar 623E scraper, and a fully loaded Caterpillar 637E scraper.

The analysis determined the tensile stresses generated in the invert section of each pipe as a result of each of the individual loadings. In CIPCP, the invert section is generally the weakest section of the pipe and tensile cracking typically begins there first. If the calculated tensile stresses did not exceed the allowable tensile stress, then the loading conditions for the pipe were considered acceptable.

SOIL CONDITIONS

CIPCP relies much on the adjacent soils in its ability to carry heavy vertical loads. As a result, soil conditions play a key role in the loading analysis of CIPCP. The soil conditions at the Chandler Airport as reported by WTI were used in the analysis (see the appendix).

The soils used in this analysis are typically described by the Unified Soils Classification system as ML/CL and SM/SC of low PI, otherwise known as "potato dirt" by the local contractors. These clayey and silty sands usually are very dense, have a PI approximately equal to 5, and stand-up well after excavated. A unit weight of 130 pcf was used in this analysis.

The most important soil property is the coefficient of passive earth pressure. This property alone has a profound influence on CIPCP's load carrying capability. With an expected internal angle of friction of 34 degrees (this angle was taken from figure 18.1 of Soil Mechanics in Engineering Practice by Terzaghi and Peck), the coefficient of passive earth pressure was calculated to to be 3.6 using the Rankine formula. But the value of this coefficient occurs at state of plastic equilibrium in the soil which is never reached. The strains in the pipe required to reach this state in the soil are much greater than the strains needed to damage the pipe. In practice, a range of 0.7 to 1.0 is used for the earth pressure coefficient or Rankine ratio (k) which is based on actual field measurements and past experience. For these calculations, a value of K = 0.9 was used. (This based on a load test program done in similar soils in California as reported by Gilley, Gabriel and Standley in a paper titled, "Field Test of 72-inch Diameter CIPCP" presented at the ASCE International Conference of Pipeline Design and Installation on March 27, 1990.)

LOADING CONDITIONS

There are two types of vertical loads on pipes placed at shallow depths. The first is the earth load which is the weight of the soil cover and paving materials placed above the pipe. The second is the live loads which are the weight of vehicles passing over the pipe. The Concrete Pipe Handbook (CPH) was referenced in configuring and calculating these loads.

Earth Loads

Because CIPCP is installed below grade in a "trench condition," the Spangler equation is used to calculate the soil loading. Refer to page 4-4 of the CPH for a description of this equation.

A unit weight of 134 pcf was assumed for the soil above the pipe because it is expected that native material will be use for pipe backfill and that construction traffic will compact this soil to at least 100% of its maximum dry density.

The following table lists the calculated earth loads on each size of pipe for 1.5' and 2' of cover:

Weight of Soil (lbs./ft. of pipe)

	1.5" Cover	2.0" Cover
24"	425	551
36"	660	862

Live Loads

The live load calculations were performed in accordance with the method described on pages 4-38 through 4-43 of the CPH, which is an accepted method by AASHTO. Using this method, dual wheel loads of tractor-trailers were assumed to have a single contact area which increases at a rate of 1 3/4 to 1 as the load propagates below the surface. Scraper loads, which are already single wheel loads, were assumed to propagate at the same rate below the surface.

For the H20 loading, only a single axle configuration was assumed because of the pipes' very close proximity to the surface. All pipe loads have a 20% impact factor added to them as required by AASHTO. The Caterpillar Performance Handbook, 19th ed. was used to calculate the scraper wheel loads.

The following tables summarize the wheels loads used and the resulting loads on each size of pipe:

Wheel Loads at Surface

	Load (lbs.)	Contact Area (width x length)
H20	16,000	20" x 10"
623E	33,507	29" x 16"
637E	47,707	37" x 21"

Loads on Pipe (lbs./l.ft.) with 1.5' of Cover

	H20	623E	637E
24" pipe	2,150	3,352	3,926
36" pipe	2,780	4,353	5,097

Loads on Pipe (lbs./l.ft.) with 2.0' of Cover

	H20	623E	637E
24" pipe	1,807	2,710	3,184
36" pipe	2,451	3,633	4,271

These pipe loads are based on construction traffic crossing the pipe transversely. Construction traffic running along the alignment of the pipe or crossing at a skew to the pipe would reduce the loads on the pipe.

LOAD SUPPORT ANALYSIS OF CIPCP

As was mentioned earlier, CIPCP relies heavily on the adjacent soils for the pipe's ability to carry significant vertical loads. These loads produce bending moments in the pipe which are counteracted by lateral thrusts and moments from the soil. The magnitude of these thrusts and moments are dependent on the unit weight of the soil, the soil's earth pressure coefficient, the radius of the pipe and its wall thickness. Formulas presented in Chapter V of the Lynch Manual for CIPCP are used to calculate the magnitude of these resisting thrusts and moments.

Failure of CIPCP is defined as a condition where the tensile stresses in any part of the pipe exceeds the allowable tensile stress of the concrete matrix. Concrete is very weak in tension. Without reinforcing steel, only several hundred psi of tensile stress are needed to crack concrete. CIPCP fails in tension when vertical loads bend the walls of the pipe sufficiently to produce tensile cracks in either the inside crown or invert. Usually the invert is more vulnerable, and the formulas in the Lynch Manual calculate the stresses at this location.

The ultimate tensile stress of the concrete used in this analysis was 520 psi. The maximum allowable stress permitted in the pipe was 400 psi which includes a factor of safety of 1.3 recommended by the Lynch Manual (400 = 520/1.3).

The following tables indicate the maximum tensile stress at the pipe invert calculated for each loading condition. Calculated tensile stresses which exceed the 400 psi allowable stress are highlighted in the tables.

Calculated Maximum Tensile-Flexural Stress (psi) with 1.5' of Cover

	H20	623E	637E
24" pipe	297	**542**	**658**
36" pipe	210	**423**	**524**

Calculated Maximum Tensile-Flexural Stress (psi) with 2.0' of Cover

	H20	623E	637E
24" pipe	200	383	**479**
36" pipe	137	297	384

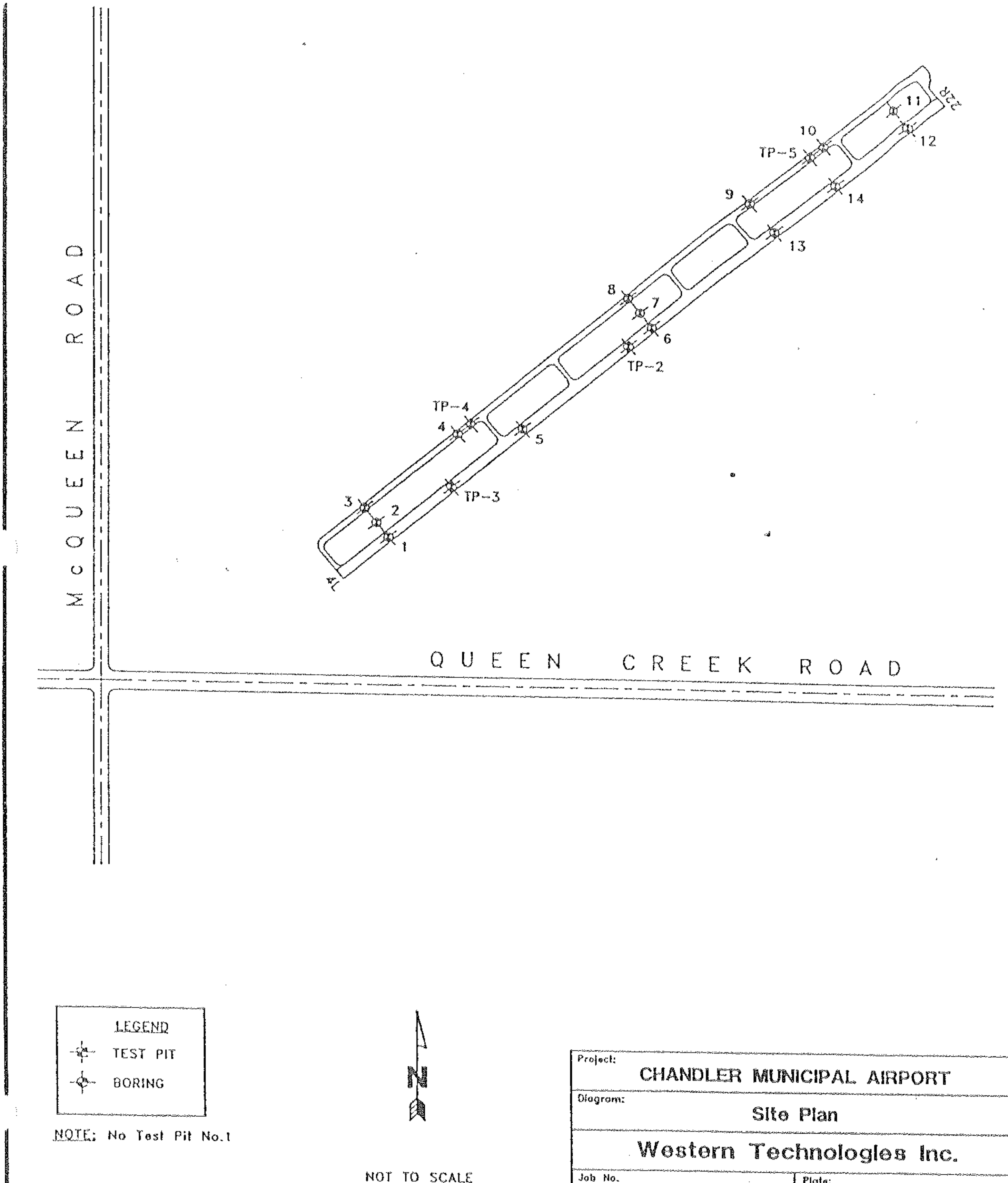
CONCLUSIONS AND DISCUSSION

Under the H20 maximum highway loading and with as little as 1 1/2 feet of cover, the calculated maximum stresses in both the 24" and 36" diameter CIPCP are well below the allowable tensile stress of 400 psi. However, the story is different under scraper loadings. Neither pipe size can tolerate fully loaded scrapers with only 1 1/2 feet of cover. But with 2 feet of cover, the 36" pipe appears to handle both types of scraper loads, while the 24" appears to handle only the lighter 623E scraper load.

It is interesting to note that for a given loading condition, the calculated maximum tensile stress decreases significantly as the pipe size increases. For example, at 1 1/2 feet of cover under a 637E loading, the maximum tensile stress on the 24" CIPCP was calculated at 658 psi, while for the 36" it was 524 psi - a 20% reduction. Yet the total load increased approximately 30% from 3926 lbs./ft. to 5097 lbs./ft. (see table at top of the previous page). The explanation for this behavior is found in the bending moments developed in CIPCP under vertical loads. For a 50% increase in pipe size (from 24" to 36"), the bending moment developed in the pipe by the vertical loads approximately doubles in magnitude. However for that same increase in pipe size, the bending moment developed by the pipe to counter the vertical loads increases over 2 1/2 times. Thus as the pipe size increases, its capacity to carry heavier loads increases exceedingly more. This confirms the observations of contractors and engineers in the field who have run fully loaded scrapers over the larger diameter pipes (48" and up) with as little as one foot of cover (and sometimes no cover) and caused no damage.

As long as impact loads can be avoided (there's no steel in CIPCP to absorb the high tensile stresses), the larger diameter CIPCPs can usually handle construction traffic loads with a reasonable amount of cover. On the other hand, the smaller diameter CIPCPs are susceptible to construction traffic loads and adequate cover for the type of loading experienced is necessary.

APPENDIX



NOTE: No Test Pit No.1

Project: CHANDLER MUNICIPAL AIRPORT	
Diagram: Site Plan	
Western Technologies Inc.	
Job No. 2123JF195	Plate: 1

The number shown in "LOG OF BORING NO. [illegible] pproximate location of the same number indicated on the "Site Plan" as positioned in the field by pacing from property lines and/or existing features.

"TYPE/SIZE BORING" refers to the exploratory equipment used in the boring wherein HSA = hollow-stem auger.

"R" in "Blows/Foot" refers to the number of blows of a 140-pound weight, dropped 30 inches, required to advance a 2.42-inch-inside-diameter ring sampler a distance of 1 foot. Refusal to penetration is considered more than 50 blows per foot.

"Sample Type" refers to the form of sample recovery, in which N = Split-barrel sample, R = Ring sample, G = Grab Sample.

"Dry Density, pcf" refers to the laboratory-determined dry density in pounds per cubic foot.

"Water Content, %" refers to the laboratory-determined moisture content in percent (ASTM D2216).

"Unified Classification" refers to the soil type as defined by "Method of Soil Classification". The soils were classified visually in the field and, where appropriate, classifications were modified by visual examination of samples in the laboratory and/or by appropriate tests.

These notes and boring logs are intended for use in conjunction with the purposes of our services defined in the text. Boring log data should not be construed as part of the construction plans nor as defining construction conditions.

Boring logs depict our interpretations of subsurface conditions at the locations and on the date(s) noted. Variations in subsurface conditions and soil characteristics may occur between borings. Groundwater levels may fluctuate due to seasonal variations and other factors.

In general, terms and symbols on the boring logs conform with "Standard Definitions of Terms and Symbols Relating to Soil and Rock Mechanics" (ASTM D653).

CHANDLER MUNICIPAL AIRPORT	
Boring Log Notes	
WESTERN TECHNOLOGIES INC.	
Job No: 2123JF195	Plate: A1

DATE DRILLED: 07-30-1993

LOCATION: See Site Plan

BORING NUMBER: 2

ELEVATION: Not Determined

MOISTURE CONTENT (% OF DRY WT)	DRY DENSITY (LBS/CU.FT)	SAMPLE TYPE	SAMPLE	BLOWS/FT.	DEPTH	USCS	GRAPHIC	SOIL DESCRIPTION
		G				ML/CL		CLAYEY SILT/SANDY CLAY; trace gravel, brown, slight to medium moist
7.5	108	R		45		SP		SAND; trace of clay and gravel, brown, dense, medium moist
		G			5			
						SC		CLAYEY SAND; some gravel
					10			Boring Stopped At 10 Feet

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION ... JR.

SPT - STANDARD PENETRATION TEST S - SHELBY TUBE
R - RING SAMPLE (2.40 in. I.D.)
C - DYNAMIC CONEHEAD DRIVING WEIGHT: 140
B - BAG G - GRAB N - SPLIT SPOON SAMPLER

NOTES:
Boring advanced with CME 45 truck mounted drill rig. No groundwater encountered.

CHANDLER MUNICIPAL AIRPORT

Boring Log

WESTERN TECHNOLOGIES INC.

Job No: 2123JF195 | Plate: A4

PHYSICAL PROPERTIES OF SOILS

Client: GILBERTSON ASSOCIATES INC
ATTN DAVID GILBERTSON, P.E.
23733 N SCOTTSDALE RD, SUITE B
SCOTTSDALE AZ 85255-3465

Job No. 2123JF195
Lab/Inv. No. 2123W195-2
Report Date: 08-27-93
Reviewed by: [signature]

Project: Chandler Municipal Airport
Location: Runway/Taxiway Chandler Municipal Airport
Material: Sandy Clay w/Trace of Gravel — Sampled By: WT/Meier — Date 07-30-93
Source: Boring 2 (0-4 feet) — Submitted By: WT/Elnicky — Date 08-02-93
Authorized By: GAI/Gilbertson — Date 07-93

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
2"		
1-1/2"		
1-1/8"		
1"		
3/4"	100	
1/2"	100	
3/8"	100	
1/4"	100	
No. 4	100	
8	100	
10	100	
16	99	
30	96	
40	93	
50	87	
100	69	
200	52	

Moisture Density Relations, pcf (ASTM D698 Method B)

Maximum Dry Density, pcf	117.0
Optimum Moisture, %	13.3

Plasticity Index, ASTM D4318

Liquid Limit	19
Plasticity Index	5

Copies to: Addressee (3)
GAI.001s:2

DATE DRILLED: 07-30-1993

LOCATION: See Site Plan

BORING NUMBER: 7

ELEVATION: Not Determined

MOIST CONTENT (% OF DRY WT)	DRY DENSITY (LBS/CU.FT)	SAMPLE TYPE	SAMPLE	BLOWS/FT.	DEPTH	USCS	GRAPHIC	SOIL DESCRIPTION
		G				SM/SC		SILTY SAND/CLAYEY SAND; trace gravel, brown, slightly moist
		R		50/10"				very dense
					5			
						SP		SAND; trace clay and gravel, brown, slightly moist
					10			Boring Stopped At 10 Feet

T - STANDARD PENETRATION TEST S - SHELBY TUBE
R - RING SAMPLE (2.40 in. I.D.)
C - DYNAMIC CONEHEAD DRIVING WEIGHT: 140
B.- BAG G - GRAB N - SPLIT SPOON SAMPLER

NOTES:
Boring advanced with CME 45 truck mounted drill rig. No groundwater encountered.

CHANDLER MUNICIPAL AIRPORT

Boring Log

WESTERN TECHNOLOGIES INC.

Job No: 2123JF195 | Plate: A9

PHYSICAL PROPERTIES OF SOILS

Client: GILBERTSON ASSOCIATES INC
ATTN DAVID GILBERTSON, P.E.
23733 N SCOTTSDALE RD, SUITE B
SCOTTSDALE AZ 85255-3465

Job No. 2123JF195

Lab/Inv. No. 2123W195-2

Report Date: 08-27-93

Reviewed by: M. Kuntzelman

Project: Chandler Municipal Airport

Location: Runway/Taxiway Chandler Municipal Airport

Material: Sandy Clay w/Trace of Gravel — Sampled By: WT/Meier — Date 07-30-93

Source: Boring 7 (0-4 feet) — Submitted By: WT/Elnicky — Date 08-02-93

Authorized By: GAI/Gilbertson — Date 07-93

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
2"		
1-1/2"		
1-1/8"		
1"		
3/4"	100	
1/2"	100	
3/8"	100	
1/4"	100	
No. 4	100	
8	100	
10	100	
16	99	
30	96	
40	92	
50	84	
100	57	
200	38	

Moisture Density Relations, pcf (ASTM D698 Method B)

Maximum Dry Density, pcf	119.4
Optimum Moisture, %	12.1

Plasticity Index, ASTM D4318

Liquid Limit	21
Plasticity Index	5

Copies to: Addressee (3)
GAI.001s:4

DATE DRILLED: 07-30-1993
LOCATION: See Site Plan

BORING NUMBER: 11
ELEVATION: Not Determined

MOISTURE CONTENT (% OF DRY WT)	DRY DENSITY (LBS/CU.FT)	SAMPLE TYPE	SAMPLE	BLOWS/FT.	DEPTH	USCS	GRAPHIC	SOIL DESCRIPTION
		G			0	SM/SC		SILTY SAND/CLAYEY SAND; trace gravel, brown, slight to medium moist
		R		50/10"				very dense
					5			
						SC		CLAYEY SAND; trace gravel, brown, slightly moist
					10			Boring Stopped At 10 Feet

PT - STANDARD PENETRATION TEST   S - SHELBY TUBE
R - RING SAMPLE (2.40 in. I.D.)
C - DYNAMIC CONEHEAD   DRIVING WEIGHT: 140
B - BAG   G - GRAB   N - SPLIT SPOON SAMPLER

NOTES:
Boring advanced with CME 45 truck mounted drill rig. No groundwater encountered.

CHANDLER MUNICIPAL AIRPORT
Boring Log
WESTERN TECHNOLOGIES INC.
Job No: 2123JF195   Plate: A13

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION